Renewable and Sustainable Energy Reviews 14 (2010) 1925–1936

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Development model for energy crop plantations in the Czech Republic for the years 2008–2030

Kamila Havlíčková *, Jiří Suchý

Department of Phytoenergy, Silva Tarouca Research Institute for Landscape and Ornamental Gardening, Publ. Res. Inst., Květnové nám. 391, 252 43 Průhonice, Czech Republic

ARTICLE INFO

Article history:
Received 30 November 2009
Accepted 9 March 2010

Keywords:
Fast-growing trees
Permanent grassland
Non-woody Energy crops
Cultivation areas

ABSTRACT

This paper deals with modelling the development of plantations for intentional biomass production. The model of plots for the areas of interest consider the following biomass sources: intentionally produced biomass from SRC of fast-growing trees and non-woody energy crops (sorrel, reed grass and triticale). Statistical data for the entire area of interest (NUTS1 size) and data for a part of this area (NUTS3 size—18% of total area of interest) were used to determine data on the area of arable land and permanent grasslands in the initial year. This paper presents a model of the development of production plots for the period 2008–2030. Yields are calculated of selected energy crops with regard to their growing cycle using so-called triangular method. The core of the algorithm for calculation of growing area of energy crop is an optimalization of processes regarding economic and technical demands for long-term and sustainable production of biomass.

Contents

1. Introduction

Renewable energy sources (RES) continue to play an important role in the energy policies of developed countries. Many reasons for this exist. Because renewables substitute classic fossil fuels they help lower greenhouse gases and lower the risks connected to climate change. Renewable energy use also has many other advantages. Recently the question of energy security has become an increasingly important aspect of renewable use. Developed countries, as can be seen in the EU, are highly dependent on imported primary energy sources, often from potentially politically or economically unstable areas. This dependence creates many risks, especially economic and political-strategic. The local

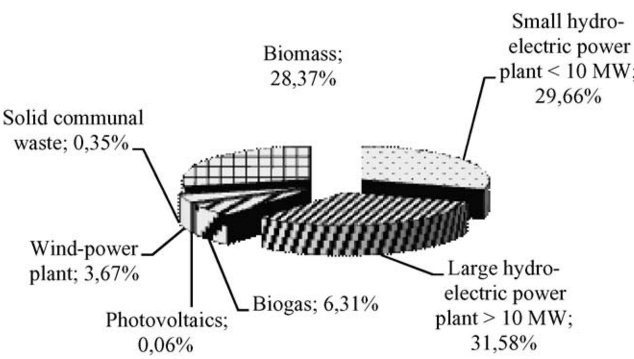
* Corresponding author. Tel.: +420 296528267; fax: +420 267750440.
E-mail addresses: havlickova@vukoz.cz (K. Havlíčková), suchy@vukoz.cz (J. Suchý).

1364-0321/$ – see front matter
doi:10.1016/j.rser.2010.03.010

accessibility of renewable sources partially counters these strategic problems.

The indicative RES targets for each member state stems from Directive 2001/77/EC on the promotion of electricity produced from renewable energy sources in the internal electricity market. These national targets are defined as the percentual share of electricity generated from renewable energy sources (RES-E) in the gross domestic electricity consumption for each member state. The Czech indicative target is set at 8% by 2010. Only 4.7% of the domestic electricity consumption was covered by the gross production of electricity from renewable sources in 2007. Renewables covered 3.9% of primary energy sources (PES) in 2007. This estimate reflects energy contained in fuel used and does not consider the effectiveness of technologies.

Graph Electricity produced from renewable sources in 2007 in the Czech Republic.



Source: Report on progress on National indicative goal fulfilment of electricity production from renewables for year 2007 [4,19].

The development of renewables use is accompanied by the need to solve a wide range of questions and problems concerning, e.g., renewables technologies, basic limits of the individual renewable sources (e.g., dependence on environmental conditions, specifics of connecting to the energy grid and eventually storing energy supply), biomass cultivation methods, energy potentials, which individual renewable sources can contribute to the primary energy source balance for a given area, etc. Last but not least, the economics of the use of individual renewable sources, and the determination of effective methods to provide incentives, either direct or indirect, to support renewable energy sources are also important questions of renewables development.

In the valid Czech State Energy Policy, biomass is considered to be a decisive, dominant renewable energy source. Various barriers limit the current development. One of the most significant barriers to biomass production is the absence of consistent mapping of the potential of individual biomass forms. Resolving this problem would enable the formulation of a strategy for biomass use that could serve as a document for revising the energy policy and simultaneously for actualizing the financial incentives scheme.

From the technically utilizable potential point of view, biomass is the most perspective of the renewable energy sources for electricity and heat production in the Czech Republic. Its use is technically well managed and no problems arise from an instable supply as is with wind, solar or hydroenergy. The stability of supply can be maximalized by combining biomass with non-renewable fuels. The main and difficult to overcome limit to biomass use is its amount on the market and transport accessibility.

In the mid- and long-term, biomass is the decisive RES for the Czech Republic. The production of electricity from biomass increased from 731 GWh in 2006 to 968 GWh in 2007. This increase was partially caused by the increase in the number of new producers using cogeneration of biomass with coal. In 2007 a total of 665,000 t of biomass were used to produce electricity, which is markedly more than in 2006 (512,000 t). The increase was recorded mainly for forest residuals, saw dust and chips. The energy content of biomass used to produce electricity was 7358 TJ [1].

Biomass sources currently are mainly residual or waster material, i.e., straw from various cereal grains or rapeseed, or wood chips from forests or wood-working businesses. With the expected development of bioenergy, it is evident that there will not be enough waste or residual biomass and that the biomass supply will need to be supplemented with intentionally planted energy crops.

Currently the Czech Republic has about 4,264,000 ha of agricultural lands, almost 54% of the country's total area. More than a third of the Czech lands are forested. Since 1995 the amount of agricultural lands has decreased by 15,000 ha and the amount of forests has increased by about 16,000 ha. While over the past 10 years the amount of arable land has been decreasing, the amount of land registered as permanent grasslands has increased by about 71,000 ha. Half of the agricultural land is found in less-fortunate areas (LFAs) that are less suitable for production, but may be used for energy crop production.

2. Materials and methods

The main data sources for the development model of production plots for intentionally produced biomass are annual reports and data from the Czech Statistical Office (plant production, size of the area of interest, and land use structure), Green Reports of the Ministry of Environment, and results and outputs of research on energy crops.

The model considers the following biomass sources: SRC of fast-growing trees and non-woody energy crop stands.

2.1. Short rotation coppice (SRC) of fast-growing trees

SRC of fast-growing trees in Czech conditions are plantations of the most suitable clones of poplars or willows. The basic characteristics of these plantations include a 20–25-year plantation life cycle, harvest every 3–5 years, gradual increase in biomass yields from the plantation with the optimum being reached between the 8th and 12th year. The plantations are established using cuttings planted by a planting machine, and harvested using a special machine (usually a corn harvester adapted for this purpose) that directly produces wood chips [2,3,5,9].

2.2. Non-woody energy crops

The main advantage of these crops is that they can be harvested with standard harvesters. Many of them are perennials, e.g., sorrel hybrid, miscanthus, and Jerusalem artichoke. All of these crops differ from food crops in that they are produced for biomass yield and not for nutritional value.

2.3. Annual crops

Cereal crops grown for energy purposes are advantageous in that biomass can be produced without large capital investments in new harvesting technologies. A typical annual crop considered as an energy crop is triticale.

Triticale is a cross between rye and wheat with good yields even in less suitable conditions. It is an undemanding cover crop that tolerates soils with unsuitable pH and is disease and pest resistant. The straw from triticale has a heating capacity of 15.1 GJ/t at 15% moisture content [7].

2.4. Perennial crops

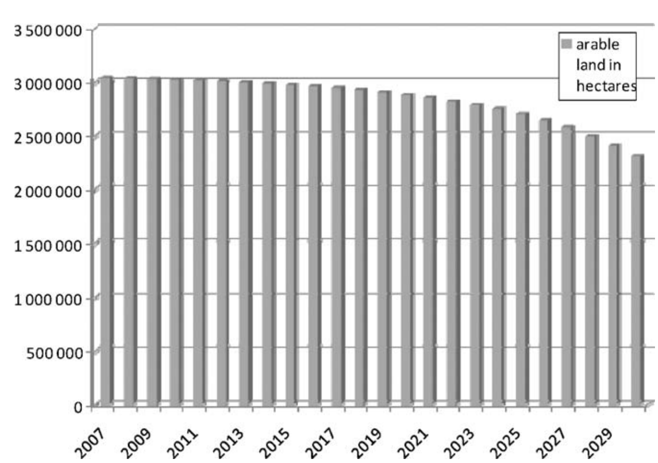
Reed canary grass is a water- and nutrient-demanding perennial grass. It is resistant to poor climatic conditions. As an energy crop, reed canary grass should be harvested after winter when the plant contains less water (12–25% water content). Dry matter loss during winter is reported to be around 25% of total weight. Reed canary grass is harvested in the spring when it has around 20% moisture content and a heating capacity of 12.52 GJ/t. Reed canary grass stands are low-maintenance needing only supplemental fertilizing. They last 5–8 years with plants reemerging after harvest.

The sorrel hybrid (Uteush) is a cross between English spinach (Rumex patientia L.) and Tien Shan sorrel (Rumex tianschanicus A.Los.). This crop is a high quality animal feed that can be harvested when green 2–3 times a year. If it is not harvested when green, it grows into tall highly branched stalks. The sorrel hybrid is a perennial plant that can last up to 10 years, which from a phytoenergetics point view is extremely advantageous. This sorrel hybrid is a robust tall plant that provides yields of 5–7 t (dry matter)/has already in the second year after being planted. The production technologies for growing this sorrel hybrid as an energy crop have been sufficiently elaborated for the Czech Republic and indicate the sorrel hybrid's perspective use. The sorrel hybrid is harvested when it has about 25% moisture content and a heating capacity of 12.17 GJ/t.

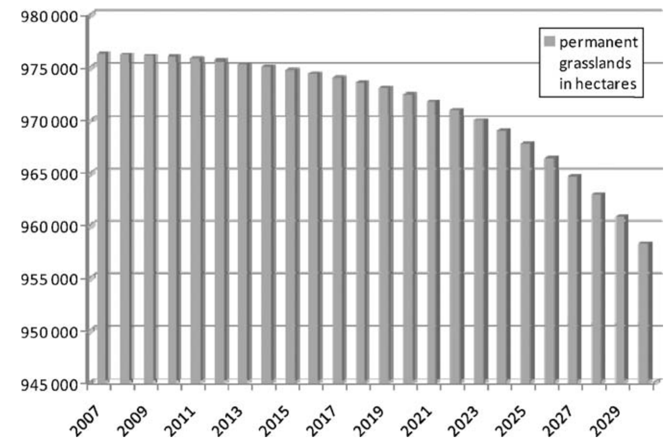
For all of these non-woody energy crops the biomass obtained (unless we consider, e.g., harvesting green material as an input for biogas stations) is baled (middle-sized or huge bales).

To model the development of biomass production sites we must first determine the size of the region of interest, and then determine the area of arable land and permanent grasslands (in hectares) in the model's startup year. This can be found, e.g., on the NUTS1 level (whole Czech Republic) from data from the Czech Statistical Office—http://www.czso.cz/. The model's startup year is usually considered the actual year. Then, we must determine the area (in hectares) that is being considered for biomass production (SRC and non-woody energy crops) in the last year of the model for this entire area of interest (e.g., in agreement with the State Energy Policy to attain EU targets).

Materials from the Ministry of the Environment that were documents of the State Energy Policy in 2004 were used when modelling the size of plots in the area suitable for energy crop production. In these materials, energy crop production in 2030



Graph 1. Development of transformation of arable lands for energy crop and SRC production in Czech Republic from 2008 to 2030. *Note:* Data on area are given in absolute numbers (total area in hectares).



Graph 2. Development of transformation of permanent grasslands for energy crop and SRC production in Czech Republic from 2008 to 2030. *Note:* Data on area are given in absolute numbers (total area in hectares).

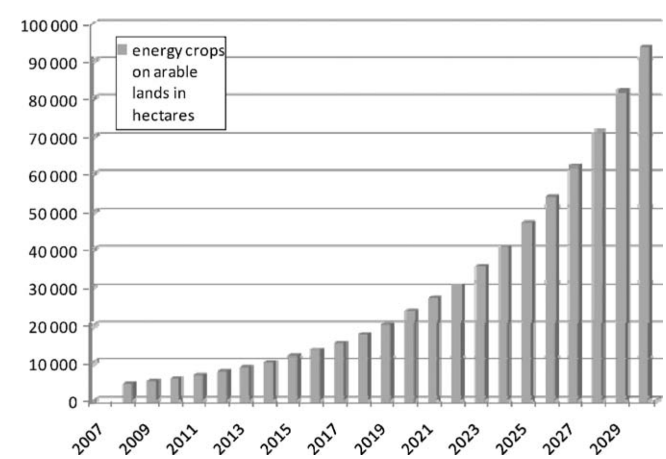
would be on 750,000 ha, of this 60,000 ha were targeted for SRC of fast-growing trees.

On the basis of this obtained information about the startup size of the area of interest, the number of years considered in the model and the area targeted for energy crop production we can consider which trend will the final area of biomass attain. If we want to establish the same size energy crop plots each year we would need to have enough available land, suitable equipment and enough seed and planting material (e.g., from mother orchards for SRC) available already in the startup year.

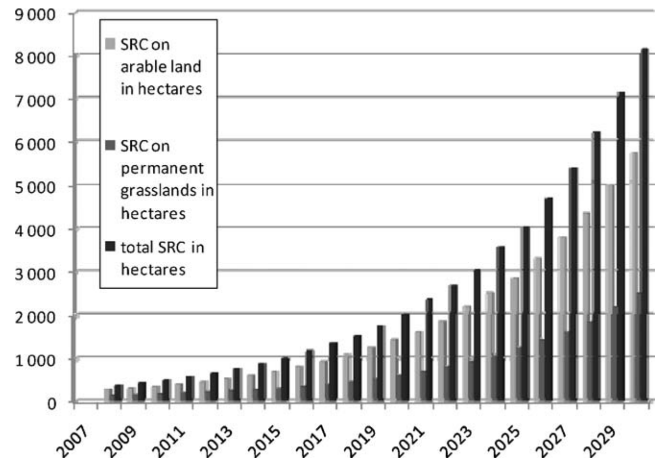
A much more advantageous course of action would be to gradually increase the number of plantations being established each year. In our model geometric sequencing is used because according to our experience this ensures a fluent increase in supply of planting materials, the releasing of lands for energy crop production and purchasing/renting of equipment.

3. Results

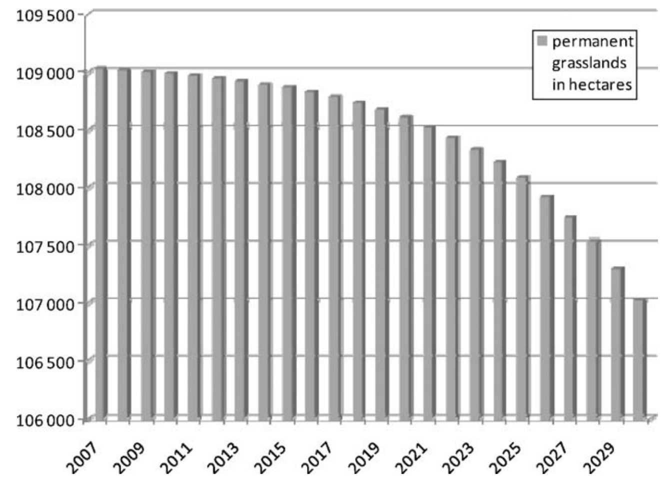
- Model period: 2008–2030.
- Total area of arable lands in the Czech Republic in 2007 (year before the model's startup year): **3,039,669** ha.
- Total Czech area suitable for SRC and non-woody energy crops in the model's last year (2030): **750,000** ha.



Graph 3. Increase in area of energy crop plantations in the Czech Republic from 2008 to 2030. *Note:* absolute numbers are relative, i.e., each year is characterized by an increase in the amount of land used for energy crop production. Absolute numbers can be obtained by adding the increase for the given years.



Graph 4. Annual increase in SRC plantations of fast-growing trees in the Czech Republic from 2008 to 2030. *Note:* absolute numbers are relative, i.e., each year is characterized by an increase in the amount of land used for energy crop production. Absolute numbers can be obtained by adding the increase for the given years.



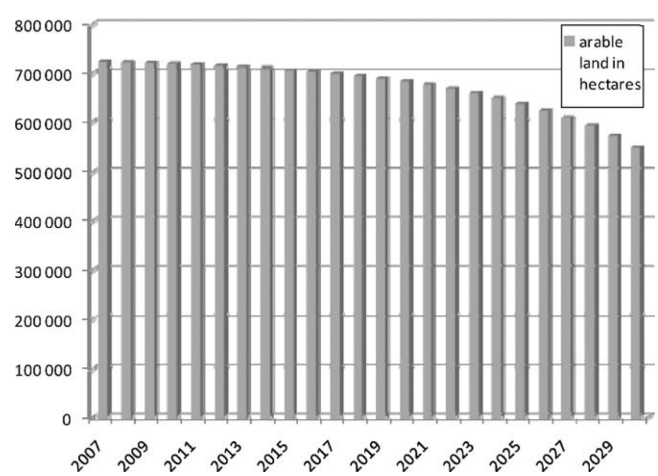
Graph 6. Development of transformation of permanent grasslands for energy crop and SRC use in NUTS3 (18%) from 2008 to 2030. *Note:* the trend of the transformation from arable and permanent grasslands in the Czech Republic is derived from absolute numbers, i.e., each year is characterized by the total area available for production. In the NUTS18 region, this trend has been maintained, but with a more complicated calculation because in the given NUTS area, arable lands nor permanent grasslands is not 18% of that for the entire Czech Republic.

- Area of Czech arable lands suitable for SRC and non-woody energy crops in 2030: **732,000** ha (sum **s** of geometric sequence).
- Area of Czech permanent grasslands suitable for SRC in 2030: **18,000** ha (sum **s** of geometric sequence).
- Number of terms **n** of geometric sequence will then be: $(2030 - 2008) + 1 = \mathbf{23}$.
- Coefficient of plot growth **q** of geometric sequence in the following year: **1.15**.

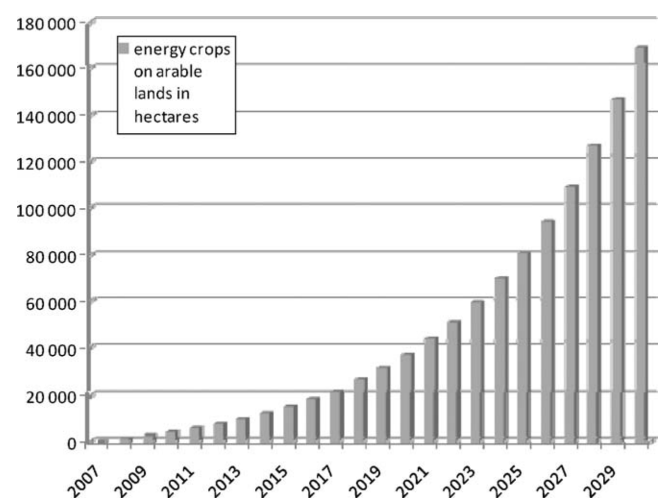
Considering that fast-growing trees can be grown even on permanent grasslands, the model assumes that 42,000 ha of arable land and 18,000 ha of permanent grasslands was used for fast-growing tree production. Sizes given are for the whole Czech Republic—on the NUTS1 level.

By adjusting formula (1) for the sum of the geometric sequencing $s = \mathbf{a}_1 \cdot (q^n - 1)/(q - 1)$ we obtain formula (2) for the first term $\mathbf{a}_1 = s \cdot (q - 1)/(q^n - 1)$, which is the size of the plantations in the model's startup year (2008).

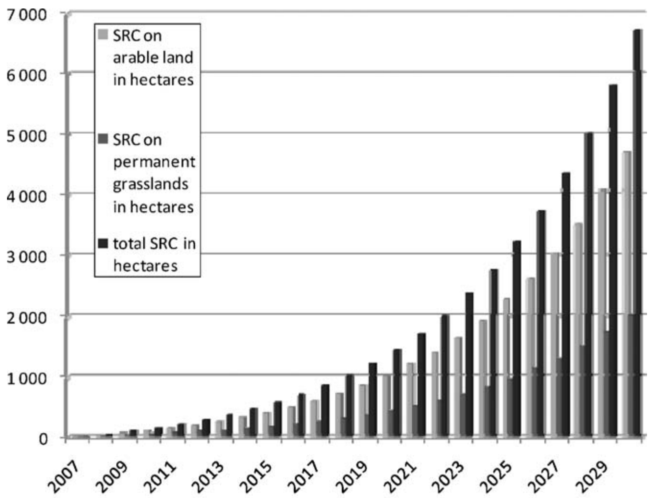
- According to formula (2) we can calculate:
- Total area of Czech arable lands suitable for SRC and non-woody energy crops in the first year in the model (2008): **4596** ha ($\mathbf{a}_1$ geometric sequencing).
- Area of Czech permanent grasslands suitable for SRC in 2008: **113** ha ($\mathbf{a}_1$ geometric sequencing).
- According to formula (3) for the **n**-th term of geometric sequencing $\mathbf{a}_n = \mathbf{a}_1 \cdot q^{n-1}$ we can calculate:



Graph 5. Development of transformation of arable land for energy crop and SRC use in NUTS3 (18) from 2008 to 2030. This principle is also valid for permanent grassland plots (TTP), when the ratio between the total TTP area for the Czech Republic and the NUTS3 (18%) area is obtained. The total TTP area for the Czech Republic is then divided by this value for each year from 2008 to 2030. *Note:* the trend of the transformation from arable and permanent grasslands in the Czech Republic is derived from absolute numbers, i.e., each year is characterized by the total area available for production. In the NUTS18 region, this trend has been maintained, but with a more complicated calculation because in the given NUTS area, arable lands nor permanent grasslands is not 18% of that for the entire Czech Republic.



Graph 7. Increase in the amount of land used for energy crops in NUTS3 (18%) from 2008 to 2030. *Note:* the trend of the transformation from arable and permanent grasslands in the Czech Republic is derived from absolute numbers, i.e., each year is characterized by the total area available for production. In the NUTS18 region, this trend has been maintained, but with a more complicated calculation because in the given NUTS area, arable lands nor permanent grasslands is not 18% of that for the entire Czech Republic.



Note: In graphs 5-8 the trend of the transformation from arable and permanent grasslands in the Czech Republic is derived from absolute numbers, i.e., each year is characterized by the total area available for production. In the NUTS-18 region, this trend has been maintained, but with a more complicated calculation because in the given NUTS area, arable lands nor permanent grasslands is not 18% of that for the entire Czech Republic.

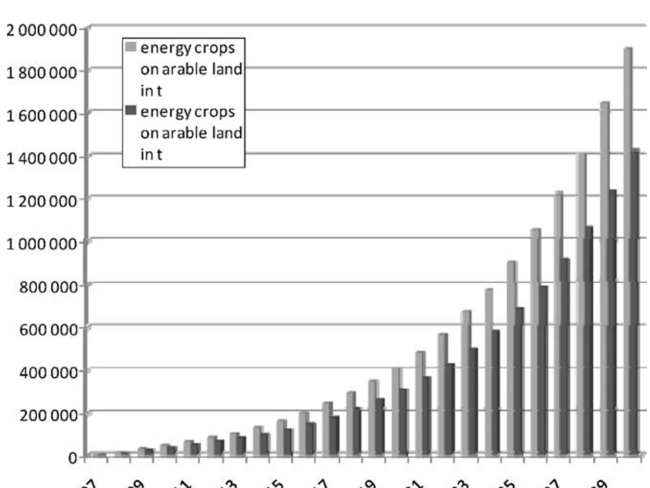
Graph 8. Increase in the amount of land used for SRC in NUTS18 from 2008 to 2030. *Note:* the trend of the transformation from arable and permanent grasslands in the Czech Republic is derived from absolute numbers, i.e., each year is characterized by the total area available for production. In the NUTS18 region, this trend has been maintained, but with a more complicated calculation because in the given NUTS area, arable lands nor permanent grasslands is not 18% of that for the entire Czech Republic.

- Increase in the total of Czech arable lands suitable for SRC and non-woody energy crops in the last year of the model (2030): **99,475** ha ($\mathbf{a}_n$ geometric sequencing).
- Increase in the area of Czech permanent grasslands suitable for SRC in 2030: **2446** ha ($\mathbf{a}_n$ geometric sequencing).

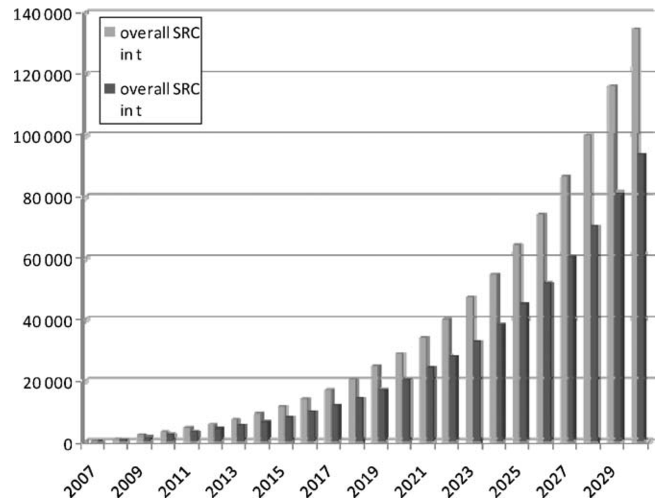
Each year then the areas (increased area for biomass production; decreased area of arable lands for conventional agriculture or permanent grasslands) change by a value of $\mathbf{a}_1 \cdot q^{n-1}$, where with an increasing $\mathbf{n}$ the value of change also increases (Graphs 1–4).

3.1. Development model of plantations for 18% of Czech Republic (NUTS3 level) from 2008 to 2030

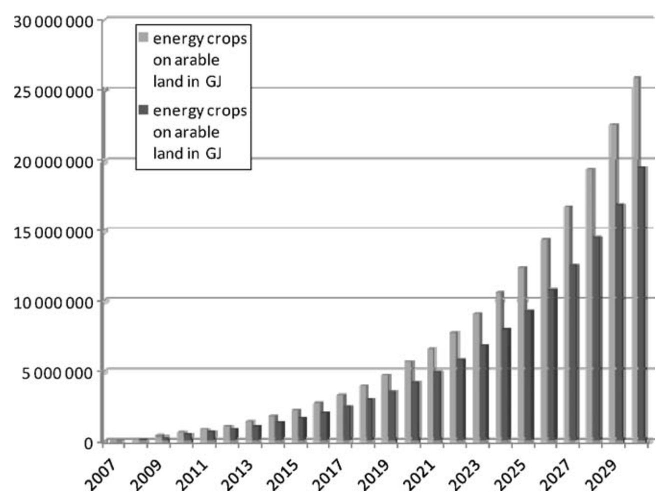
In the following model, an overview of how in a region covering about 18% of the Czech Republic, plot size of arable lands for



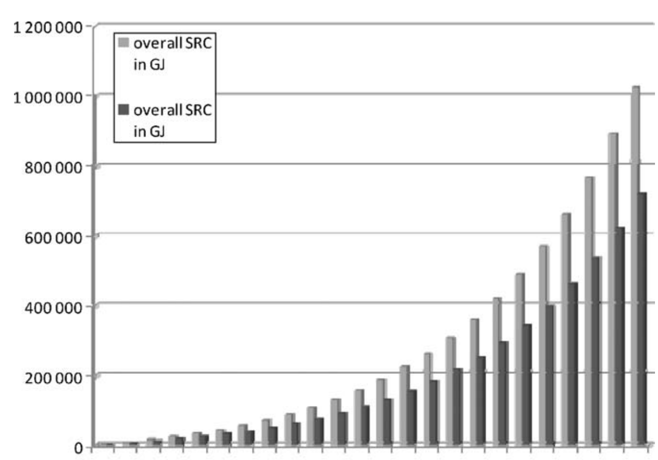
Graph 9. Comparison of yields in tonnes of energy crop material for both variants (unclear legend—which is variant I and which is variant II).



Graph 10. Comparison of yields in tonnes of SRC biomass for both variants.



Graph 11. Comparison of potentials of energy crop biomass for both variants.



Graph 12. Comparison of potentials of SRC biomass for both variants.

Table 1
Material yields of energy crops and SRC in variant I.

Year	Arable land	Permanent grasslands	Energy crops on arable land	Overall SRC in ha	Energy crops on arable land	Overall SRC in t
2007	720476	109030	0	0	0	0
2008	719387	109017	1060	42	11870	841
2009	718134	109003	2279	90	25522	1809
2010	716693	108986	3680	146	41220	2922
2011	715037	108967	5292	210	59274	4202
2012	713131	108945	7146	284	80035	5673
2013	710940	108920	9278	368	103911	7366
2014	708421	108890	11729	466	131368	9312
2015	705523	108857	14549	578	162944	11550
2016	702191	108818	17791	706	199256	14124
2017	698359	108774	21519	854	241015	17084
2018	693952	108723	25807	1024	289037	20489
2019	688884	108664	30738	1220	344263	24403
2020	683056	108596	36408	1445	407773	28905
2021	676354	108519	42929	1704	480810	34082
2022	668646	108429	50429	2002	564802	40036
2023	659782	108327	59053	2344	661392	46883
2024	649589	108209	68971	2738	772472	54757
2025	637866	108073	80376	3191	900213	63812
2026	624386	107917	93492	3711	1047115	74225
2027	608883	107737	108576	4310	1216053	86201
2028	591055	107530	125922	4999	1410331	99972
2029	570552	107293	145871	5790	1633752	115809
2030	546974	107020	168811	6701	1890685	134022

conventional agriculture and permanent grasslands will develop from 2008 to 2030. For a better idea of the scale, 18% of the Czech Republic is similar to the NUTS3 level for the Czech Republic.

The initial assumption for modelling areas is that the decrease in arable and permanent grasslands (meaning an increase in lands used for energy crops) will follow the same trend as for the entire Czech Republic.

Parameters:

- Modelling period: **2008–2030**.
- Total area of arable lands in NUTS3 (18%) in 2007 (a year before the model's startup): **720,476** ha.
- Total area of permanent grasslands in NUTS3 (18%) in 2007 (a year before the model's startup): **109,030** ha.

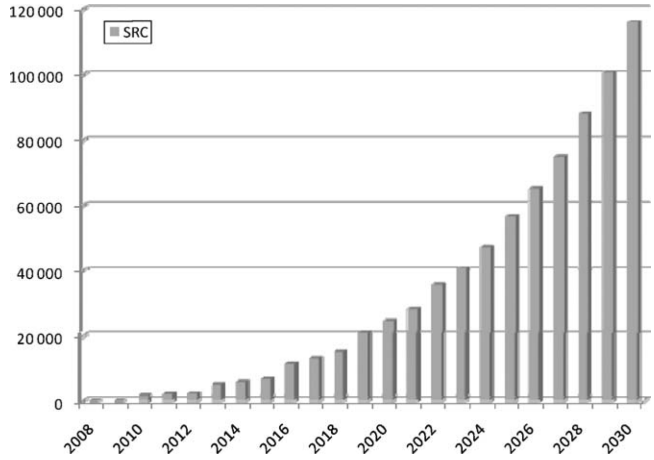
The first step is to find the ratio between the total area of arable lands in the Czech Republic to that in the NUTS3 (18%) in 2007. In the next step the value given for arable lands for the entire Czech Republic for years 2008–2030 will be divided by this given ratio (Graphs 5–8).

3.2. Calculation of yield and energy crop and SRC potential for the NUTS3 (18%) area from 2008 to 2030 using the tabular method

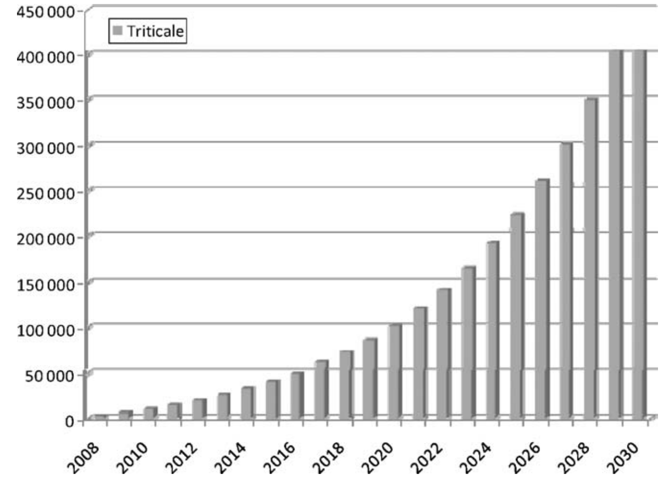
Biomass yields in tonnes are determined by multiplying production area in hectares by the average yield in tonnes/hectare. In variant I the average yield of non-woody energy crops is 11.2 t ha^{-1} at 20% moisture content and of SRC is 20 t ha^{-1} at 50% moisture content [6,7,9]. In variant II we assumed lower yields of

Table 2
Material yields of energy crops and SRC in variant II.

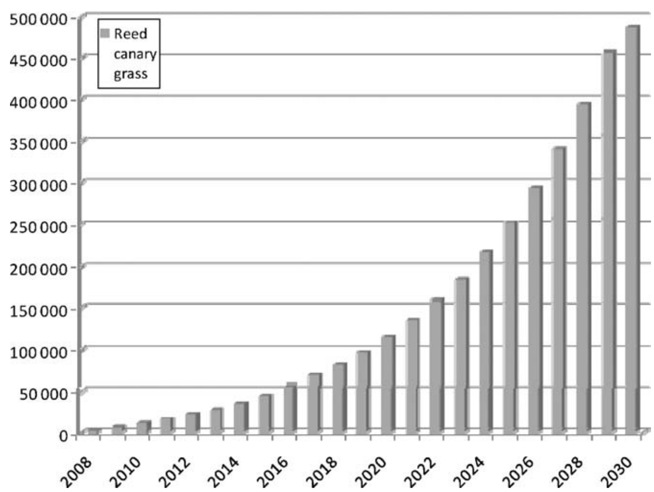
Year	Arable land	Permanent grasslands	Energy crops on arable land	Overall SRC in ha	energy crops on arable land	Overall SRC in t
2007	720476	109030	0	0	0	0
2008	719387	109017	1060	42	8903	589
2009	718134	109003	2279	90	19141	1266
2010	716693	108986	3680	146	30915	2045
2011	715037	108967	5292	210	44455	2941
2012	713131	108945	7146	284	60026	3971
2013	710940	108920	9278	368	77933	5156
2014	708421	108890	11729	466	98526	6518
2015	705523	108857	14549	578	122208	8085
2016	702191	108818	17791	706	149442	9887
2017	698359	108774	21519	854	180761	11959
2018	693952	108723	25807	1024	216778	14342
2019	688884	108664	30738	1220	258197	17082
2020	683056	108596	36408	1445	305830	20234
2021	676354	108519	42929	1704	360607	23858
2022	668646	108429	50429	2002	423601	28025
2023	659782	108327	59053	2344	496044	32818
2024	649589	108209	68971	2738	579354	38330
2025	637866	108073	80376	3191	675160	44668
2026	624386	107917	93492	3711	785336	51958
2027	608883	107737	108576	4310	912040	60340
2028	591055	107530	125922	4999	1057749	69980
2029	570552	107293	145871	5790	1225314	81067
2030	546974	107020	168811	6701	1418014	93816



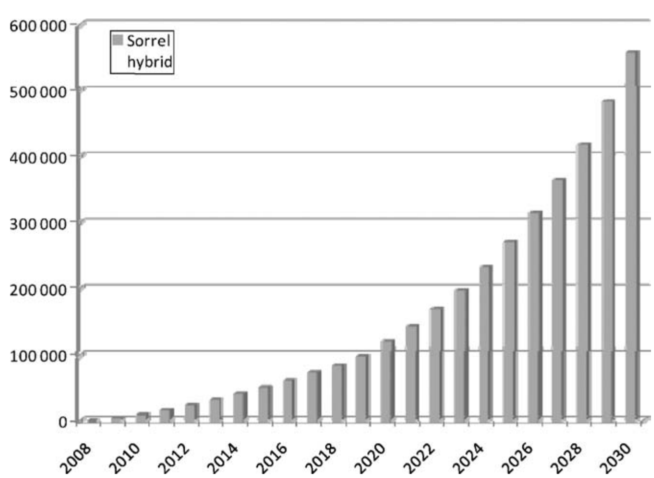
Graph 13. Biomass yield from SRC in tonnes for individual years.



Graph 16. Triticale yields in tonnes for individual years.



Graph 14. Reed canary grass biomass yields in tonnes for individual years.



Graph 15. Sorrel hybrid yields in tonnes for individual years.

intentionally produced energy crops, i.e., 8.4 t ha^{-1} at 20% moisture content for non-woody energy crops and 14 t ha^{-1} at 50% moisture content for SRC (Graphs 9–12) (Tables 1 and 2).

3.3. Calculation of biomass yield and energy crop and SRC potential for the NUTS3 (18%) area from 2008 to 2030 using the tabular method

This method aims to determine the most accurate annual yield of biomass if the according to yields curves of individual plantations) annually planted areas) (Graphs 13–16) (Tables 3–6).

3.4. Determining overall biomass potential for the NUTS3 (18%) area from 2008 to 2030

See Graphs 17 and 18.

4. Discussion and conclusions

Global use of modern biomass energy is in its infancy, especially in the transportation sector. Recently, various aspects of the production and use of bioenergy, especially so-called first-generation biofuels, have been criticized and debated in the scientific and non-scientific literature [13,14,17,18]. Food commodity prices increased sharply between 2004 and the summer of 2008, and many analysts and commentators pinpoint the market development of biofuels as one of the main causes [8,20], a key factor allegedly being the subsidized production of biofuels in the European Union and the United States (Monbiot, 2005).

Of the currently available options, many consider bioenergy to be important, because of its substantial growth potential [15,16]. In contrast with fossil fuels, use of biomass for energy (i.e. bioenergy) has the potential to reduce GHG emissions, but only if the biomass is sustainably produced [10]. It is a versatile energy source, it can be used to produce heat and power as well as solid, liquid and gaseous fuels. Due to rising prices of fossil fuels and decreasing production costs of modern bioenergy carriers, the competitiveness of bioenergy has improved considerably over the past 10 years [11,12].

Biomass production is still in the initial phases in the Czech Republic. Currently about 250 ha of fast-growing trees and approximately 1200 ha of non-woody species are being used for energy crop production. Our goal was to propose a plan for regular

Table 3
SRC biomass yields in tonnes for individual years.

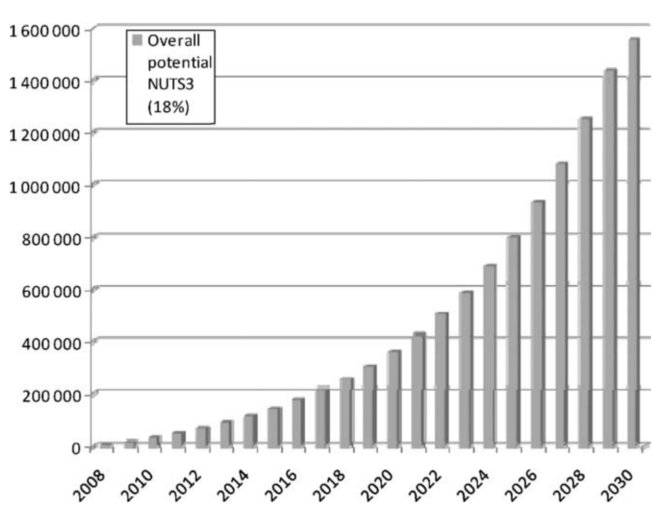
ROK		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	
2008	42																						0
2009	48																						0
2010	56	1578																					1578
2011	64		1814																				1814
2012	74			2087																			2087
2013	85	2735			2399																		5134
2014	97		3145			2759																	5904
2015	112			3617			3173																6790
2016	129	3576			4159			3649															11385
2017	148		4113			4783			4197														13092
2018	170			4729			5500			4826													15056
2019	196	3681			5439			6326			5550												20996
2020	225		4234			6255			7274			6383											24145
2021	259			4869			7193			8365			7340										27767
2022	298	3366			5599			8272			9620			8441									35298
2023	342		3871			6439			9513			11063			9707								40593
2024	394			4451			7404			10939			12723			11163							46681
2025	453	2524			5119			8515			12580			14631			12838						56208
2026	521		2903			5887			9792			14467			16826			14764					64639
2027	599			3338			6770			11261			16638			19350			16978				74335
2028	689	2019			3839			7785			12950			19133			22252			19525			87505
2029	792		2322			4415			8953			14893			22003			25590			22454		100631
2030	911			2671			5077			10296			17127			25304			29429			25822	115725
Σ	6701 ha																					Σ	757363 t

Note: Column 1 is the year of SRC establishment; column 2 is area in ha, on which the SRC of fast-growing trees was established in the given year; columns 3–21 are the yields (in tonnes of fresh biomass) in the given year considering a 3-year harvest; the last column is the sum of the yields in the given year (i.e., the yields of all SRC of fast-growing trees established to date); the model is based on a 3-year harvest cycle, a 21-year SRC life cycle and the following yields per harvest (37.5–65–85–87.5–80–60–48) t ha^{-1} fresh biomass.

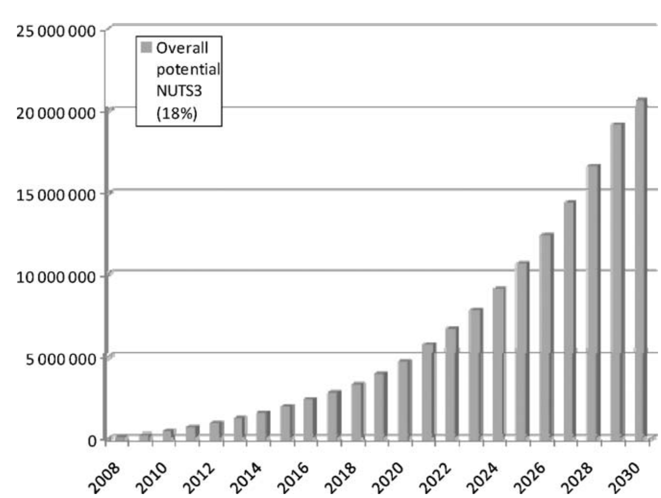
planting and development of biomass from energy crops in selected regions of the Czech Republic. As was mentioned chapter 2, it is important to select the trend that enables a gradual annual increase of areas planted with woody or non-woody energy crops. This ensures the fluent increase of planting material supply and releasing of soils for energy crop production purposes as well as acquiring planting machines.

When modelling the amount of individual biomass sources supplied throughout the year until 2030 we must consider the specific type of energy crop being produced. The calculations needed to included the actual energy crop yields for each harvest period. When selecting the energy crop we must consider whether the selected crop could be grown on large areas in the Czech Republic, and whether enough planting material and seed for stand establishment exists or can be obtained. Using these criteria we selected the following energy crops as suitable for the Czech Republic: SRC of fast-growing trees, sorrel hybrid, reed canary grass and triticale.

The model could be expanded to include even other grasses, e.g., miscanthus, that could have similar yield parameters. Miscanthus was not included in the model because enough planting material is not available in the Czech Republic and miscanthus stand establishment is relatively costly. It can be expected that the development of financial incentives for establishing stands in the Czech Republic could lead to increased use of this interesting energy crop.



Graph 17. Total yield in tonnes of energy crop and SRC biomass for individual years.



Graph 18. Total yield in GJ from energy crop and SRC biomass for individual years.

Table 4
Reed canary grass yields in tonnes for individual years.

ROK		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	
2008	353	1978																						1978
2009	406	3462	2275																					5737
2010	467	4105	3982	2616																				10703
2011	537	4006	4721	4579	3009																			16315
2012	618	3611	4607	5429	5266	3460																		22373
2013	711	1978	4152	5298	6244	6055	3979																	27707
2014	817	3462	2275	4775	6093	7180	6964	4576																35325
2015	940	4105	3982	2616	5491	7007	8257	8008	5263															44729
2016	1081	4006	4721	4579	3009	6315	8058	9496	9210	6052														55445
2017	1243	3611	4607	5429	5266	3460	7262	9267	10920	10591	6960													67373
2018	1429	1978	4152	5298	6244	6055	3979	8352	10657	12558	12180	8004												79457
2019	1644	3462	2275	4775	6093	7180	6964	4576	9604	12255	14442	14007	9204											94838
2020	1890	4105	3982	2616	5491	7007	8257	8008	5263	11045	14094	16608	16108	10585										113168
2021	3134	4006	4721	4579	3009	6315	8058	9496	9210	6052	12702	16208	19099	18524	12173									134150
2022	2500	3611	4607	5429	5266	3460	7262	9267	10920	10591	6960	14607	18639	21964	21302	13999								157883
2023	2875	1978	4152	5298	6244	6055	3979	8352	10657	12558	12180	8004	16798	21435	25258	24498	16098							183544
2024	3306	3462	2275	4775	6093	7180	6964	4576	9604	12255	14442	14007	9204	19318	24650	29047	28172	18513						214538
2025	3802	4105	3982	2616	5491	7007	8257	8008	5263	11045	14094	16608	16108	10585	22215	28347	33404	32398	21290					250824
2026	4372	4006	4721	4579	3009	6315	8058	9496	9210	6052	12702	16208	19099	18524	12173	25548	32599	38415	37258	24484				292453
2027	5028	3611	4607	5429	5266	3460	7262	9267	10920	10591	6960	14607	18639	21964	21302	13999	29380	37489	44177	42847	28156			339932
2028	5782	1978	4152	5298	6244	6055	3979	8352	10657	12558	12180	8004	16798	21435	25258	24498	16098	33787	43113	50804	49274	32380		392900
2029	6649	3462	2275	4775	6093	7180	6964	4576	9604	12255	14442	14007	9204	19318	24650	29047	28172	18513	38855	49580	58424	56665	37237	455297
2030	7647	4105	3982	2616	5491	7007	8257	8008	5263	11045	14094	16608	16108	10585	22215	28347	33404	32398	21290	44683	57016	67188	65164	484875
Σ	56270 ha																						Σ	3481545 t

Note: Column 1 is the year the stand of reed canary grass was established; column 2 is the size of the reed canary grass stand in ha in the year of establishment; columns 3–22 are the yields in tonnes of fresh biomass in the given year; the last column is the sum of the yields for the given year (i.e., yields from all to-date established stands); the model is based on a 5-year life cycle and the following yields (5.6–9.8–11.62–11.34–10.22) t ha^{-1} fresh biomass.

Table 5
Sorrel hybrid yields in tonnes for individual years.

ROK		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	
2008	353																							0
2009	406	3180																						3180
2010	467	4239	3657																					7896
2011	537	5299	4875	4205																				14380
2012	618	5299	6094	5607	4836																			21836
2013	711	5299	6094	7008	6448	5561																		30411
2014	817	4239	6094	7008	8060	7415	6395																	39212
2015	940	3710	4875	7008	8060	9269	8527	7355																48803
2016	1081	3180	4266	5607	8060	9269	10659	9806	8458															59303
2017	1243	3180	3657	4906	6448	9269	10659	12258	11277	9726														71378
2018	1429		3657	4205	5642	7415	10659	12258	14096	12969	11185													82085
2019	1644	3180		4205	4836	6488	8527	12258	14096	16211	14914	12863												97577
2020	1890	4239	3657		4836	5561	7461	9806	14096	16211	18642	17151	14793											116453
2021	2174	5299	4875	4205		5561	6395	8580	11277	16211	18642	21439	19724	17012										139220
2022	2500	5299	6094	5607	4836		6395	7355	9867	12969	18642	21439	24654	22682	19563									165403
2023	2875	5299	6094	7008	6448	5561		7355	8458	11348	14914	21439	24654	28353	26084	22498								195513
2024	3306	4239	6094	7008	8060	7415	6395		8458	9726	13050	17151	24654	28353	32606	29997	25873							229079
2025	3802	3710	4875	7008	8060	9269	8527	7355		9726	11185	15007	19724	28353	32606	37496	34497	29753						267150
2026	4372	3180	4266	5607	8060	9269	10659	9806	8458		11185	12863	17258	22682	32606	37496	43121	39671	34216					310402
2027	5028	3180	3657	4906	6448	9269	10659	12258	11277	9726		12863	14793	19847	26084	37496	43121	49589	45622	39349				360142
2028	5782		3657	4205	5642	7415	10659	12258	14096	12969	11185		14793	17012	22824	29997	43121	49589	57027	52465	45251			414164
2029	6649	3180		4205	4836	6488	8527	12258	14096	16211	14914	12863		17012	19563	26247	34497	49589	57027	65581	60335	52039		479468
2030	7647	4239	3657		4836	5561	7461	9806	14096	16211	18642	17151	14793		19563	22498	30185	39671	57027	65581	75419	69385	59845	555627
Σ	56270 ha																						Σ	3708681 t

Note: Column 1 is the year of sorrel hybrid stand establishment; column 2 is the size of the stands in ha established in the given year; columns 3–22 are the yields in tonnes of fresh biomass for the given year; the last column is the sum of the yields for the given year (i.e., yields from all to-date established stands); the model is based on a 10-year life cycle (with no harvest in the first year) and with the following yields (9–12–15–15–15–12–10.5–9–9) t ha^{-1} fresh biomass.

Table 6
Triticale biomass yields for individual years.

ROK		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	
2008	353	2932																						2932
2009	406	2932	3372																					6304
2010	467	2932	3372	3878																				10182
2011	537	2932	3372	3878	4460																			14642
2012	618	2932	3372	3878	4460	5129																		19771
2013	711	2932	3372	3878	4460	5129	5898																	25668
2014	817	2932	3372	3878	4460	5129	5898	6783																32451
2015	940	2932	3372	3878	4460	5129	5898	6783	7800															40251
2016	1081	2932	3372	3878	4460	5129	5898	6783	7800	8970														49221
2017	1243	2932	3372	3878	4460	5129	5898	6783	7800	8970	10315													59536
2018	1429	2932	3372	3878	4460	5129	5898	6783	7800	8970	10315	11863												71399
2019	1644	2932	3372	3878	4460	5129	5898	6783	7800	8970	10315	11863	13642											85041
2020	1890	2932	3372	3878	4460	5129	5898	6783	7800	8970	10315	11863	13642	15688										100730
2021	2174	2932	3372	3878	4460	5129	5898	6783	7800	8970	10315	11863	13642	15688	18042									118771
2022	2500	2932	3372	3878	4460	5129	5898	6783	7800	8970	10315	11863	13642	15688	18042	20748								139519
2023	2875	2932	3372	3878	4460	5129	5898	6783	7800	8970	10315	11863	13642	15688	18042	20748	23860							163380
2024	3306	2932	3372	3878	4460	5129	5898	6783	7800	8970	10315	11863	13642	15688	18042	20748	23860	27439						190819
2025	3802	2932	3372	3878	4460	5129	5898	6783	7800	8970	10315	11863	13642	15688	18042	20748	23860	27439	31555					222374
2026	4372	2932	3372	3878	4460	5129	5898	6783	7800	8970	10315	11863	13642	15688	18042	20748	23860	27439	31555	36288				258662
2027	5028	2932	3372	3878	4460	5129	5898	6783	7800	8970	10315	11863	13642	15688	18042	20748	23860	27439	31555	36288	41732			300394
2028	5782	2932	3372	3878	4460	5129	5898	6783	7800	8970	10315	11863	13642	15688	18042	20748	23860	27439	31555	36288	41732	47991		348385
2029	6649	2932	3372	3878	4460	5129	5898	6783	7800	8970	10315	11863	13642	15688	18042	20748	23860	27439	31555	36288	41732	47991	55190	403576
2030	7647	2932	3372	3878	4460	5129	5898	6783	7800	8970	10315	11863	13642	15688	18042	20748	23860	27439	31555	36288	41732	47991	55190	403576
Σ	56270 ha																						Σ	3067586 t

Note: Column 1 is the year of establishing the triticale stand; column 2 is the size of the area in ha established in the given year; columns 3–22 are the yields in tonnes of fresh biomass in the given year; the last column is the sum of the yields for the given year (i.e., yields from all to-date established stands); it is assumed that the yields throughout 2008–2030 will be the same, i.e., 8.3 t ha^{-1}.

Acknowledgements

These results were obtained under grant SP/3g1/24/07 ''Methodology and analysis of biomass potential in the Czech Republic'' financed from the research and development fund of the Ministry of the Environment of the Czech Republic.

References

[1] Havlíčková K, Knápek J, Vašíček J. The economics of short rotation coppice. In: Proceedings of the 2nd World Conference Biomass for Energy, Industry and Climate Protection. Rome: ETA Florence and WIP-Munich; 2004. p. 561–564, ISBN 88-89407r-r04-2.
[2] Agrobränsle, AB, Stig L, Overview of Experiences with Coppice Plantations of Fast—Growing Tree Species in Biomass Production in Sweden; 2003.
[3] Weger J, Havlíčková K. The first results of the selection of woody species for short rotation coppices in the transitional oceanic-continental climate of the Czech Republic. In: Twelfth European Conference Biomass for Energy, Industry and Climate Protection. Amsterdam: ETA Florence; 2002. p. 107–110.
[4] Zpráva o plnění indikativního cíle výroby elektřiny z OZE za rok; 2007.
[5] Weger J, Vlasák P, Zánová I, Havlíčková K. The results of the evaluation of selected willow and poplar clones for short rotation coppice (SRC) in second and third harvesting period in conditions of the Czech Republic. In: Proceedings of the 14th European Conference Biomass & Exhibition for Energy, Industry and Climate Protection. Paris: ETA Florence; 2005.
[6] Havlíčková K, Knápek J, Vašíček J, Weger J. Biomasa obnovitelný zdroj energie—ekonomické a energetické aspekty. Acta Pruhoniciana, 2005;79, VÚKOZ, Průhonice, 67 s. ISBN 80-85116r-r38-3.
[7] Havlíčková K, Weger J, a kol. Metodika analýzy potenciálu biomasy jako obnovitelného zdroje energie. Acta Pruhoniciana 83, VÚKOZ, Průhonice, 2006;71 s. ISBN 80-85116r-r48-0.
[8] BBC. ''Inflación en alimentos limita a la ONU''; 2007. http://news.bbc.co.uk/hi/spanish/specials/2007/clime/newsid_7085000/7085227.stm.
[9] Calle FR, Groot P, Hemstock SL, Woods J. The biomass assessment handbook. London: Bioenergy for a Sustainable Environment, Earthscan; 2007.
[10] Dornburg V, Faaij A, Verweij P, Langeveld H, Ven GWJ, van de Wester P, Keulen H, van Diepen K, van Meeusen MJG, Banse MAH, Ros J, Vuuren D, van Born GJ, van den Oorschot M, van Smout F, Vliet J, van Aiking H, Londo M, Mozaffarian H, Smekens H. In: Lysen E, Egmond S, van, editors. Climate Change Scientific Assessment and Policy Analysis. Biomass Assessment of global biomass potentials and their links to food, water, biodiversity, energy demand and economy: inventory and analysis of existing studies. Utrecht, the Netherlands: Utrecht University, Wageningen University, Netherlands Environmental Assessment Agency, Free University Amsterdam; 2008 . Supporting document, Report 500102014, p. 220.
[11] Faaij APC, Schlamadinger B, Solantausta Y, Wagener M. Large scale international bio-energy trade. In: Proceedings 12th European Conference and Technology Exhibition on Biomass for Energy, Industry and Climate Change Protection; 2002.
[12] Hall DO, Rao KK. Photosynthesis: studies in biology. Cambridge: Cambridge University Press; 1999.
[13] Henke J, Klepper G, Schmitz N. Tax exemption for biofuels in Germany: is bioethanol really an option for climate policy? Energy Journal 2005;30:2617–35.
[14] Moore A. Biofuels are dead: long live biofuels? Part one. New Biotechnology 2008;25(1):6–12.
[15] OECD/IEA. World energy outlook 2008. In: International energy agency, organisation for economic co-operation and development; 2008.p. 1–578.
[16] OECD/IEA. Energy technology perspectives 2008. In support of the G8 plan of action, scenarios and strategies to 2050. In: International energy agency, organisation for economic cooperation and development; 2008.p. 1–650.
[17] Patzek TW, Anti SM, Campos R, Ha KW, Lee J, Li B, Padnick J, Yee SA. Ethanol from corn: clean renewable fuel for the future, or drain on our resources and pockets? Environment Development and Sustainability 2005;7(3):319–36.
[18] Rabbinge R. De plant als fabriek van non-food. Change magazine—Special biomass issue, 2008a;4:p. 73.
[19] MPO—Ministry of Industry and Trade of the Czech Republic. Report of independent expert commission on review of energy needs of the Czech republic in long-term horizon (in Czech). Praha, The Czech Republic; 2008.
[20] Wroughton L. Biofuels major driver of food price rise; 2008, http://uk.reuters.com/article/oilRpt/idUKN28611501620080728?sp = true.